Fuels Hazard Probability Model (FlightRisk)

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ABSTRACT

FlightRisk is a fuels hazard probability model that allows users to assess hazard of a flight at discrete points in time. Utilizing the user-developed flight profile, FlightRisk creates a flight hazard scenario that graphically displays the potential hazard zone, time the flight profile remains in this zone and the probability of risk range. FlightRisk produces the norm probability of risk for the entire flight.

FlightRisk utilizes two key windows to accomplish this task:

Probability profile window – This form allows the user to input the flash point profile (flash point temperature and corresponding probability) and select a spark ignition energy distribution curve or design a user profile spark energy ignition curve.
Flight scenario window – This form accepts a flight profile (altitude vs. time) and a fuel profile (temperature vs. time) from the user, then generates the flight hazard plot.

BACKGROUND

In June 1998, FAA released a final report that documents the findings of a fuel flammability task group [1]. The scope of the report includes jet fuel definitions and specifications, jet fuel flammability data and predictive analysis models for flammability. This report led to the development of the FlightRisk software model.

FlightRisk is a Graphical User Interface (GUI) based application that assesses hazard during an entire flight based on flash point of fuel and the effective changes of fuel temperature and altitude. In order to evaluate the hazard during the entire flight, it is necessary to sum the total of $E_{ign} < E_{spark}$ from time = 0 to time = end of flight and averaging this number (P_f).

$$P_f = \sum_{t=0}^{\text{End of Flight}} (E_{ign} < E_{spark}) \text{ / total flight time} \quad (1)$$

To graphically show hazard during the flight, altitude must be extrapolated for every minute into the flight, then a range of temperatures must be determined for that altitude. The program calculates $P_{Eign < Espark}$ for each point in that range, and plots each temperature range yielding a scope of hazard. Fuel temperature vs. time of the flight is plotted and risk is shown when this line enters into the scope of hazard.
FlightRisk require a flight scenario to be input. This consists of altitude (Z) (1000 feet) vs. time (minutes) and fuel temperature(T_{fuel}) (degrees F.) vs. time (minutes). Both of these inputs assume linearity between points.

Fuel flashpoint (T_{fp}) is required and can be a single point or a distribution.
Spark probability (F_{spark}), defined as, given a spark occurs, the probability it will be at least a certain intensity, can be selected through a distribution or can be an input.

$P_{Eign\ <\ Espark}$ is determined using the following: $P_{Eign\ <\ Espark} = 1 - F_{Espark}(E_{ign})$ (2)
Where F_{Espark} is the cumulative distribution and E_{ign} is the spark energy required for ignition(Joules).

E_{ign} is determined using the following:

$$Ln(E_{ign}) = Ln(E_{ign})_{\ min} + a(T_{fuel} - T_{min})^2 \quad (3)$$
$$E_{ign} = e^{Ln(Eign)} / 1000 \quad (4)$$

Where:

$Ln(E_{ign})_{\ min} = (0.063\ Z - 1.395)/(1 - Z/67)^{0.5}$
$a = 8.66 \times 10^{-5}\ Z + 6.73 \times 10^{-3}$
$T_{min} = T_{fp} + 22 - 1.5\ Z$
Z = altitude (1000 feet)
T_{fp} = Flash point temperature (°F)

INTRODUCTION

FlightRisk is a GUI based software model that utilizes pushbuttons, dropdown menus, check boxes and a unique graphical drag editor, all which create a user friendly model environment, without limiting the power of the user's ability to develop a general or specific scenario. FlightRisk utilizes a relational database engine to store scenario data. This relationship between the front-end system and database engine allows for easy retrieval of data. FlightRisk front-end consists of four windows, utilizing two main GUI windows, which must be opened in a certain sequence. Figure 1 shows the opening window, notice that only the *Probability Series* button and *Exit* button are highlighted. Depressing the *Probability Series* button displays the first key window (probability profile window) shown in figure 2 and enables the *Flight Scenario* button. Note that although both windows are shown independently, the flight scenario window enables the processor and therefore utilizes information entered in the probability series window.

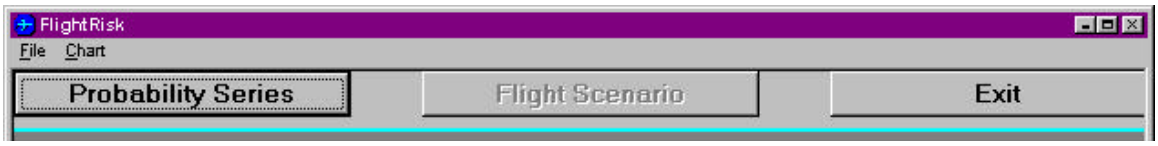


FIGURE 1. STARTUP SCREEN

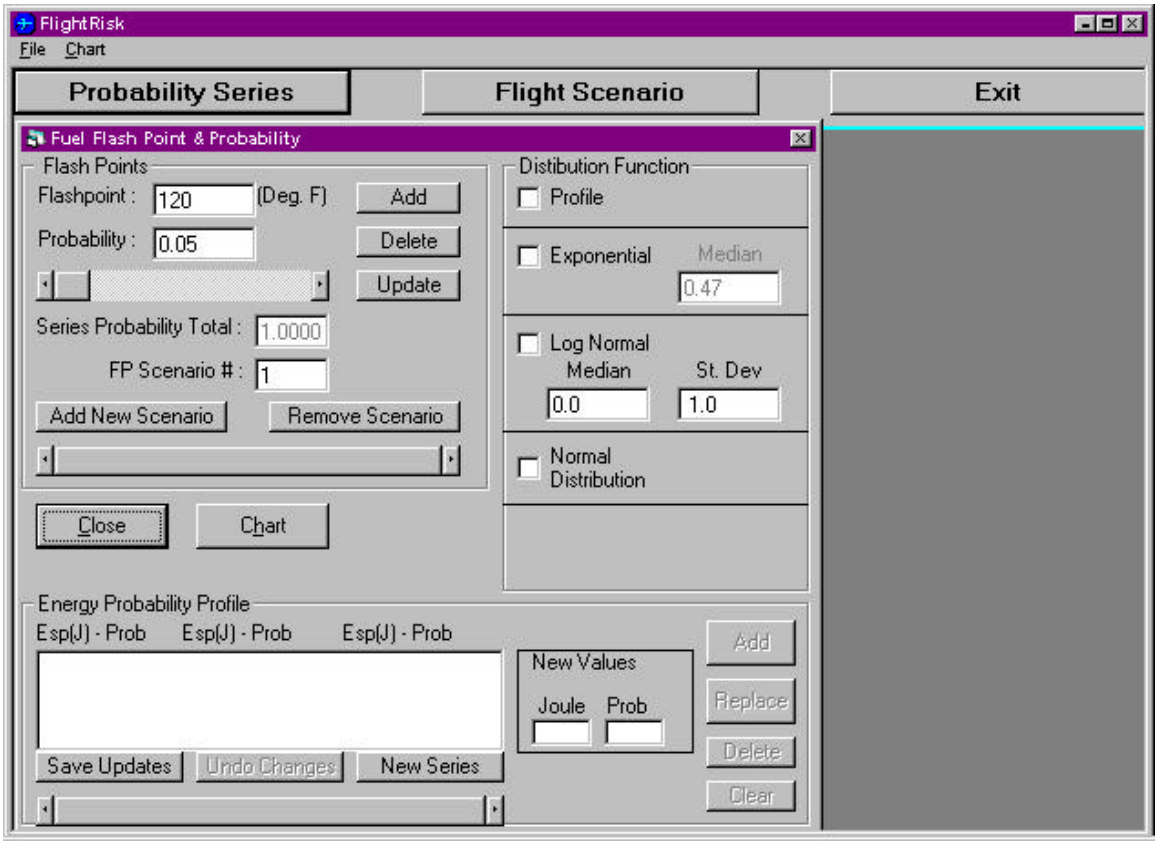


FIGURE 2. PROBABILITY PROFILE WINDOW

PROBABILITY PROFILE WINDOW

The probability profile window is designed to allow the user to enter probabilities of variables that affect the model and determine a distribution function that will support the scenario. The window displayed in figure 2 consists of three frames. The top frames must be completed correctly in order to continue. The flash points frame, figure 4, handles data input for the flash point probabilities. This frame allows the user to enter or select a flashpoint of the fuel. It also gives the user the ability to assign a distribution curve for the flashpoint. Currently assigned in the database are flashpoints of 100, 110, 120, 130, 140 and 150. Also incorporated in the database is a flashpoint distribution curve [2] shown in figure3 and table 1. The distribution function frame , figure 5, allows the user to select a probability distribution curve that will be utilized to determine the model and plot. Three of the more common distributions are included: Exponential, lognormal and normal. Optional inputs such as median and standard deviation are included if relevant to the distribution. If the user feels that the included distributions do not satisfy the criteria of the model, profile check box can be selected from the distribution function frame. This is a powerful feature included with FlightRisk, allowing the user to input a distribution profile from the energy probability profile frame, figure 6. The energy probability profile frame accepts probabilities of spark energy in Joules. The input can range from a simple on-off step function to a function containing many probabilities.

TABLE 1. FLASH POINT PROBABILITY BASED ON 1996 JET-A FUEL FLASH POINTS (NIPER).

Flash point (deg. f)	Probability
115	0.05
120	0.13
125	0.0
130	0.23
135	0.36
140	0.15
150	0.08

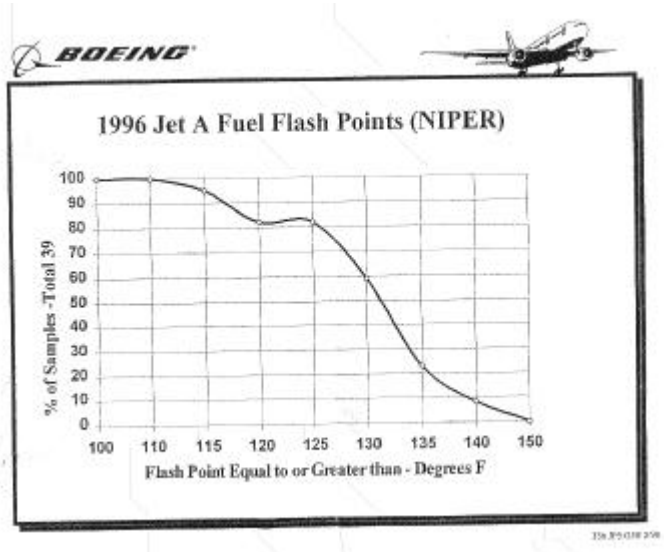


FIGURE 3. PLOT OF 1996 JET-A FUEL FLASH POINTS (NIPER).

Flash Points Frame Description
The distribution of flash points or a single point.

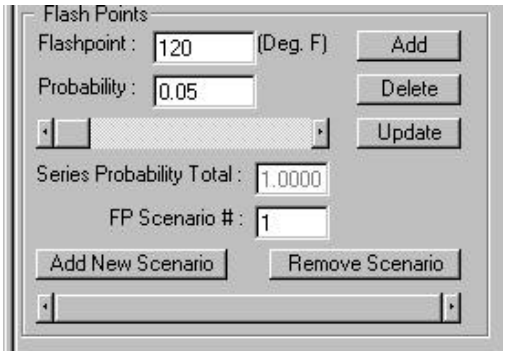


FIGURE 4. FLASH POINT FRAME

Descriptions

<Input boxes>
Flashpoint – inputs or displays flash point temperature.
Probability – inputs or displays flash point probability.
Series Probability Total – displays summation of flashpoint probability.
FP Scenario # – displays scenario from database currently selected.

<Scroll Bars>
Upper – displays each record in selected scenario.
Lower – selects scenario.

<Buttons>
Add – enters new flash point and probability in existing scenario.
Delete – deletes flash point and probability currently displayed.
Update – sets any changes to the displayed flash point and probability.
Add New Scenario – creates new scenario and blanks out flash point and probability.
Remove Scenario – deletes currently selected scenario.

Note: In order for the scenario to continue, the series probability total must equal 1.

Distribution Function Frame
Distribution function utilized to calculate explosion probability.

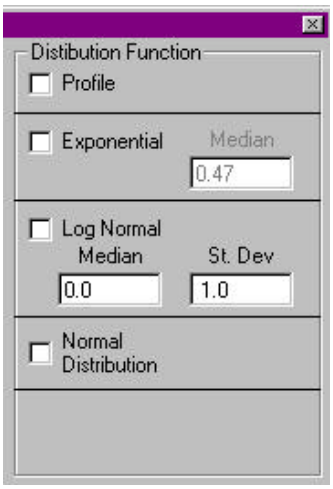


FIGURE 5. DISTRIBUTION FUNCTION FRAME

Descriptions

(One distribution function must be checked)
If *Profile* is checked, the energy probability profile frame is utilized.
Input box to change median for exponential function.
Input boxes for median and standard deviation for lognormal distribution.

Note: More than one function can be checked and charted on the probability series chart; however, only one distribution function must be checked in order to run the flight scenario.

Energy Probability Profile
User-generated distribution function.

FIGURE 6. ENERGY PROBABILITY PROFILE FRAME

Descriptions

The probability is cumulative and, therefore, should be entered in ascending order.
Note: The last probability value in the energy probability profile must contain a probability of 1.

<Input boxes>
Esp(J)-Prob – A list box displaying energy of the spark in Joules and probability.

New Values
Joule – Used to add or replace values in list box.
Prob – Used to add or replace values in list box.

<Scroll Bar> – displays profile

<Buttons>
Add – enters new Espark and probability in existing scenario.
Delete – deletes Espark and probability currently selected.
Update – sets any changes to the displayed Espark and probability.
Clear – removes all data from list.
Save Updates – permanently set changes in series.
Undo Changes – cancels modification of data and returns to previous state.
New Series – creates new series and displays the following:

Additional Options

FIGURE 7. FIRST LEVEL BUTTONS

Descriptions

Close – Close Form.
Chart – Display chart of distribution function(s) selected. (See figure 9)

FIGURE 8. SECOND LEVEL BUTTONS

Close Chart – Hides distribution function chart.
Print Chart – Sends distribution function chart to printer.

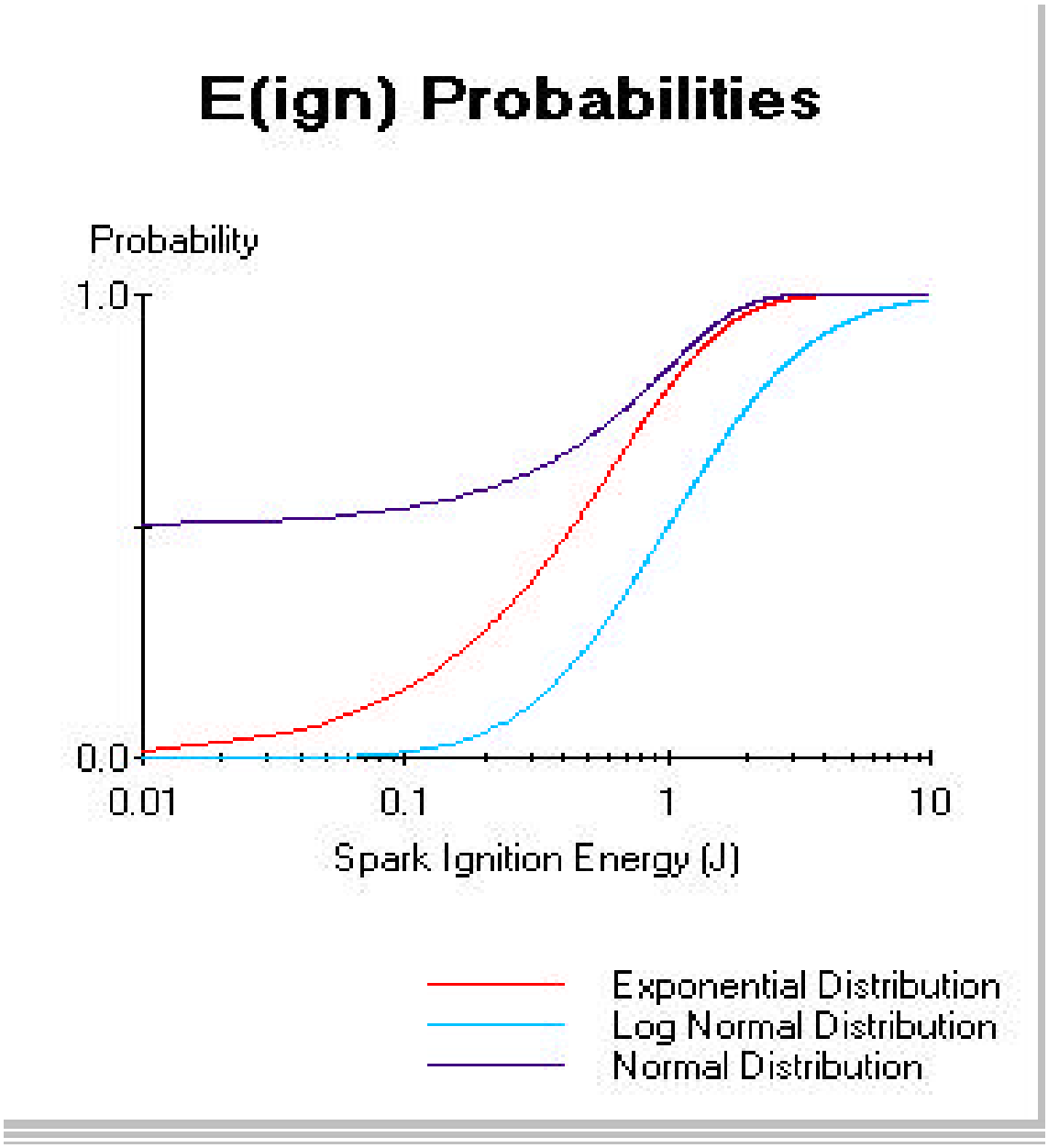


FIGURE 9. DISTRIBUTION FUNCTION CHART

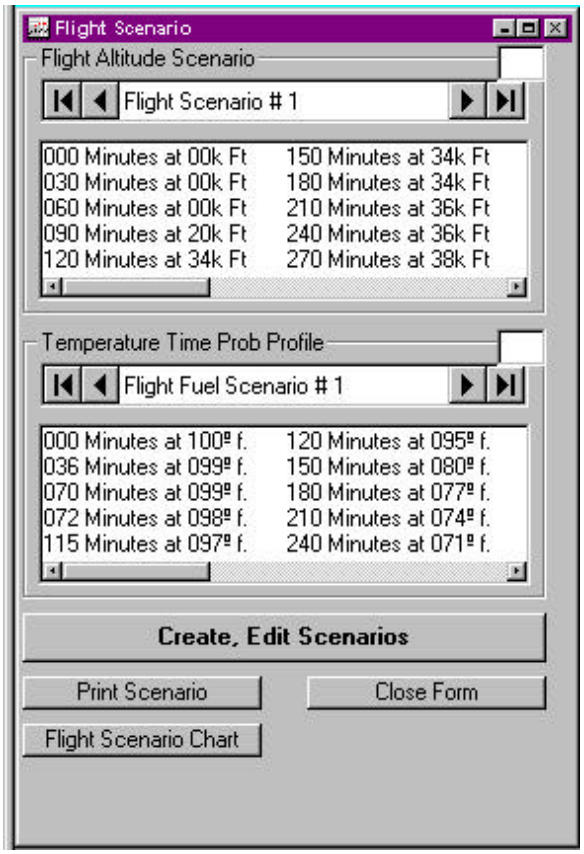


FIGURE 10. FLIGHT SCENARIO WINDOW

FLIGHT SCENARIO WINDOW

The purpose of the flight scenario window is to enter the conditions of the flight as it relates to factors of fuel risk. In addition, once the flight data is entered, the flight scenario window is where the probability model engine is initiated, and the output of the model is graphically displayed.

The initial window shown in figure 10, which is only enabled once the probability series window is initiated and data correctly entered, consists of two frames. The flight scenario frame (figure 11) allows the user to select standard flight pattern (time and altitude) that preexists in the database. The field is displayed as time in minutes and altitude as a function of 1000 feet. The temperature time prob profile frame (figure 12) allows the user to select fuel temperature, displayed in degrees F, based on time in minutes. Currently, FlghtRisk defaults to the sample data in table 2, obtained from Boeing [3]. The flight scenario chart button is enabled once data is selected. Activation of this button starts the probability model engine.

Data is entered or edited via the create, edit scenario button. This button enables the graphical drag editor window shown in figure 16.

TABLE 2. TYPICAL B747 FLIGHT ELEVATION AND TEMPERATURE PROFILE [3]

Time (Min)	T_{fuel} (deg. F)	Elevation (kft)
0	80	0
30	105	0
60	120	0
90	115	20
120	95	34
150	80	34
180	77	34
210	74	36
240	71	36
270	69	38
300	65	38
330	60	38
360	70	0

Flight Scenario Frame

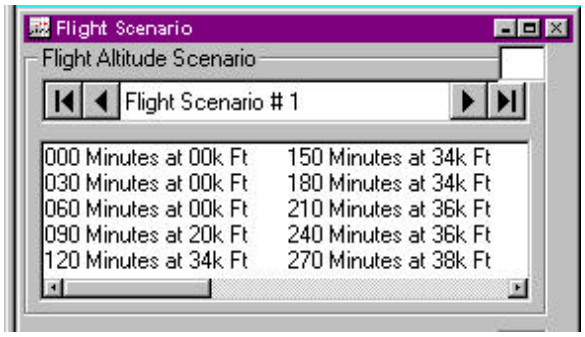


FIGURE 11. FLIGHT SCENARIO FRAME

Descriptions

<*list box*> - displays time in minutes at elevation in kfeet
(i.e., 34 = 34000 feet).

<*scroll bar*> – selects existing flight scenario from database.

Temperature Time Prob Profile

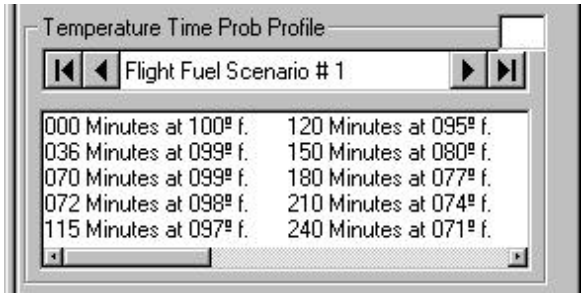


FIGURE 12. TEMPERATURE TIME PROB PROFILE FRAME

Descriptions

<*list box*> - displays minutes into flight at fuel temperature in degrees F.

<*scroll bar*> - selects existing temperature time profile in the database.

Global Buttons:

FIGURE 13. GLOBAL BUTTONS

Print Scenario – sends flight scenario and temperature time prob profile data to the printer.
Close Form – Closes flight scenario form.
Flight Scenario Chart – Processes flight scenario chart in figure 15.

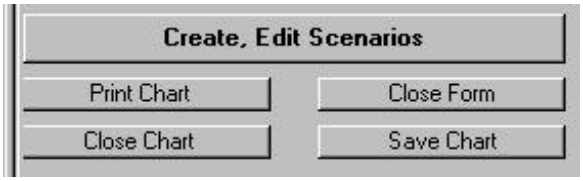


FIGURE 14. POST PLOT BUTTONS

After the chart is displayed, four option button appear (figure 14):

Print Chart – Sends flight scenario chart to printer.
Close Chart – Closes chart frame, leaves flight scenario window open.
Save Chart – Saves flight scenario chart as file with extension .OC2

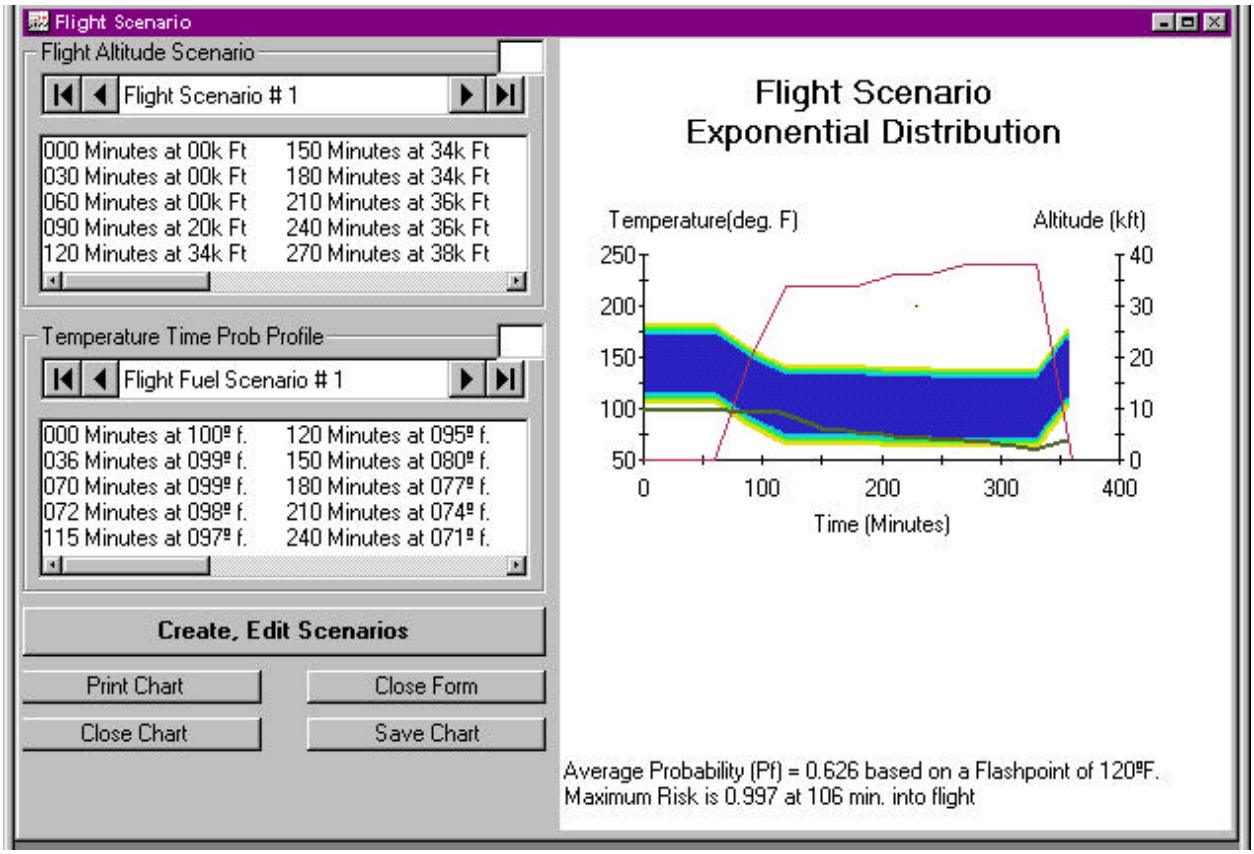


FIGURE 15. FLIGHT SCENARIO WINDOW WITH PLOT DISPLAY

GRAPHICAL DRAG EDITOR WINDOW

The graphical drag editor window (gde) in figure 16 is displayed when the create, edit scenario button is click. The gde displays the current data selected in the flight scenario window, with the fuel temperature displayed in green utilizing the left axis and the altitude displayed in blue utilizing the right axis. To edit data, the user simply clicks and holds the data point to be edited and drags it to the new position. To enter new data points, the user simply selects set altitude profile or set temperature profile, located at the bottom of the window, then using the left mouse button, clicking the location of the new data point. To delete data points, again the users simply selects the temperature or altitude profile, set the pointer to the data to be deleted and click the right mouse button.

To enter a new scenario, click the new scenario button, located in the lower right of the window, and proceed to enter the data as described above. Other option buttons included with this window are:
Set - redraws and reorganizes profiles.
Clear - erase lines and empties list boxes.
Cancel - Closes gde window and restores profiles to pre-edit.
Save & Return - Closes gde window and returns edited profiles.

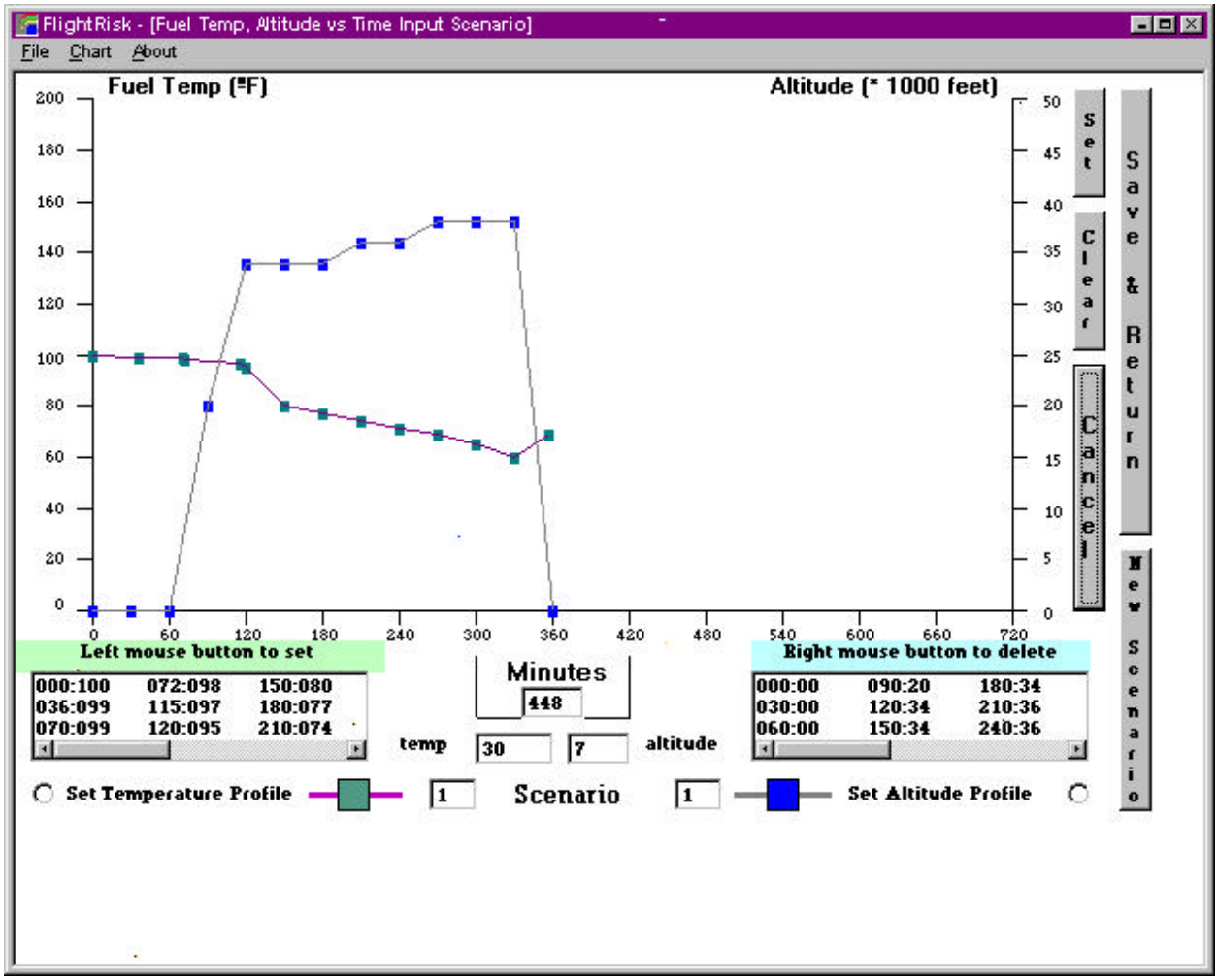


FIGURE 16. GRAPHICAL DRAG EDITOR WINDOW

OTHER OPTIONS

When all selection are made (flash point, distribution function, flight scenario, and temperature time prob profile), it is possible to save these profiles for quick recall. Under the file menu bar, select *Save* or *Save As*, enter a scenario description, and press *OK*. To recall, under file, select load profile and select profile to load.

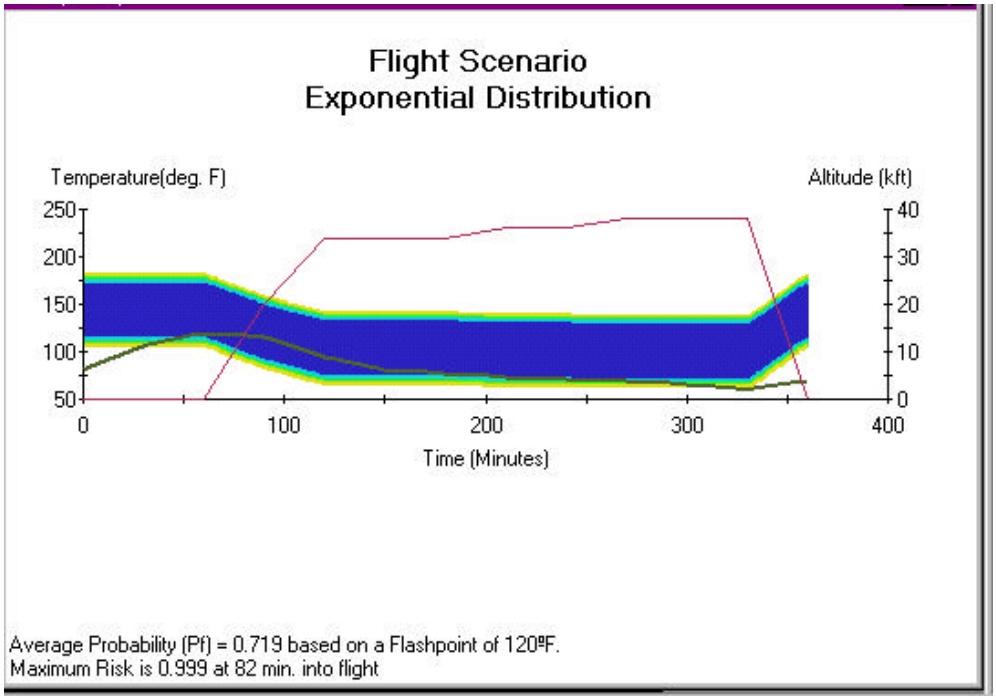
References

1. Fuel Flammability Task Group, A Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks, FAA Report DOT/FAA/AR-98/26, June 1998

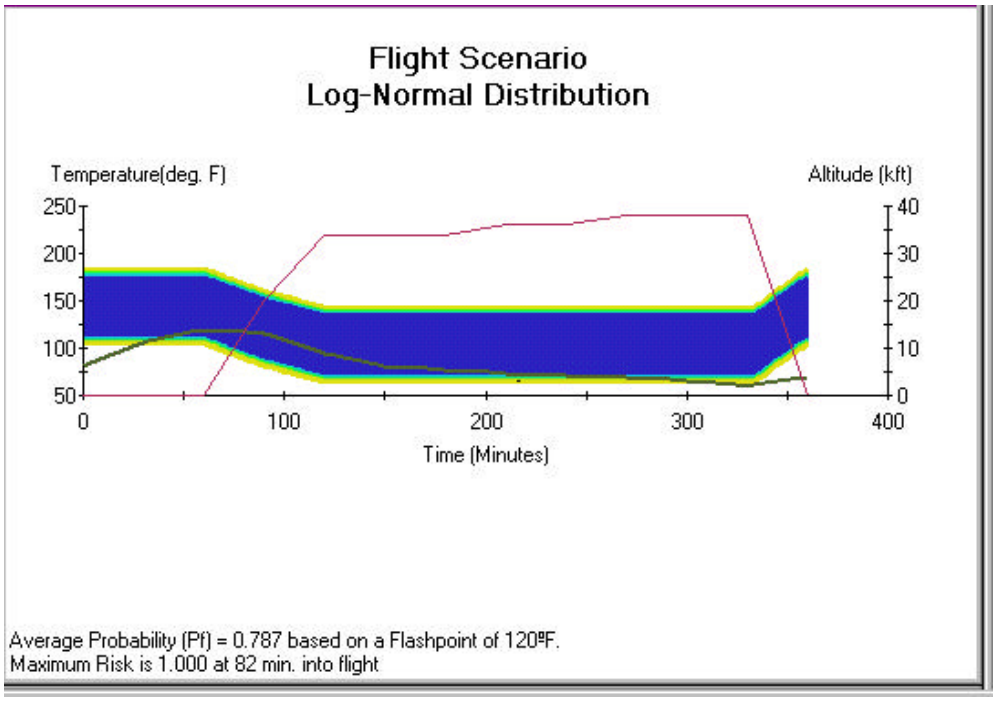
2. 1996 Jet a Fuel (NIPER), Boeing Commercial Airplane, 1996

3. Fornia, T., Thermal Modeling to Predict Fuel Tank Flammability, Boeing Commercial Airplane Group, October 7-9, 1997

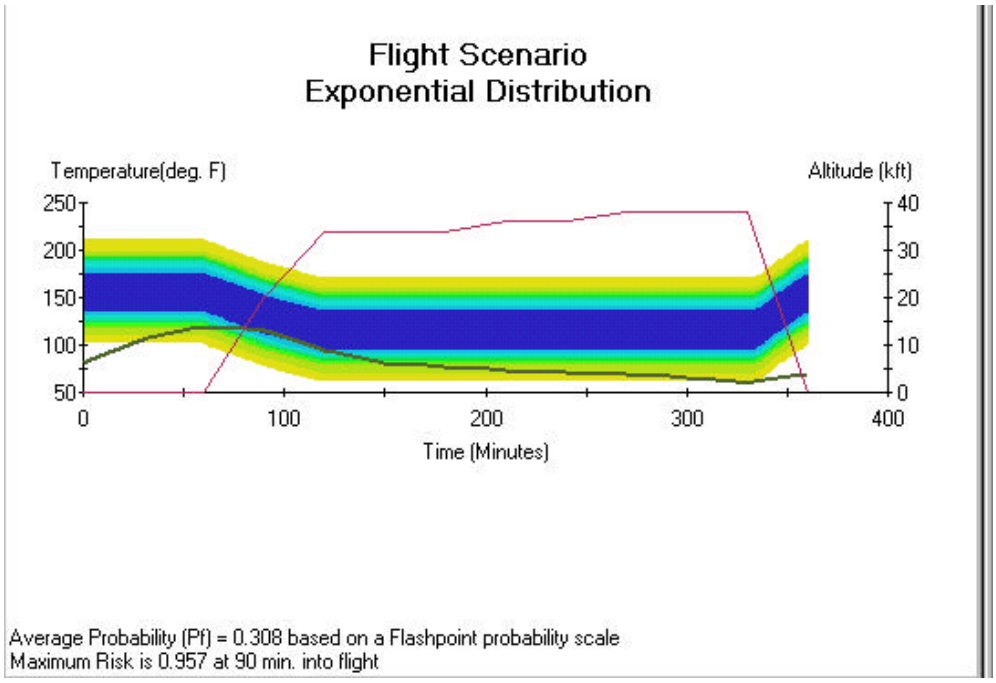
Appendix 1 : Sample Data



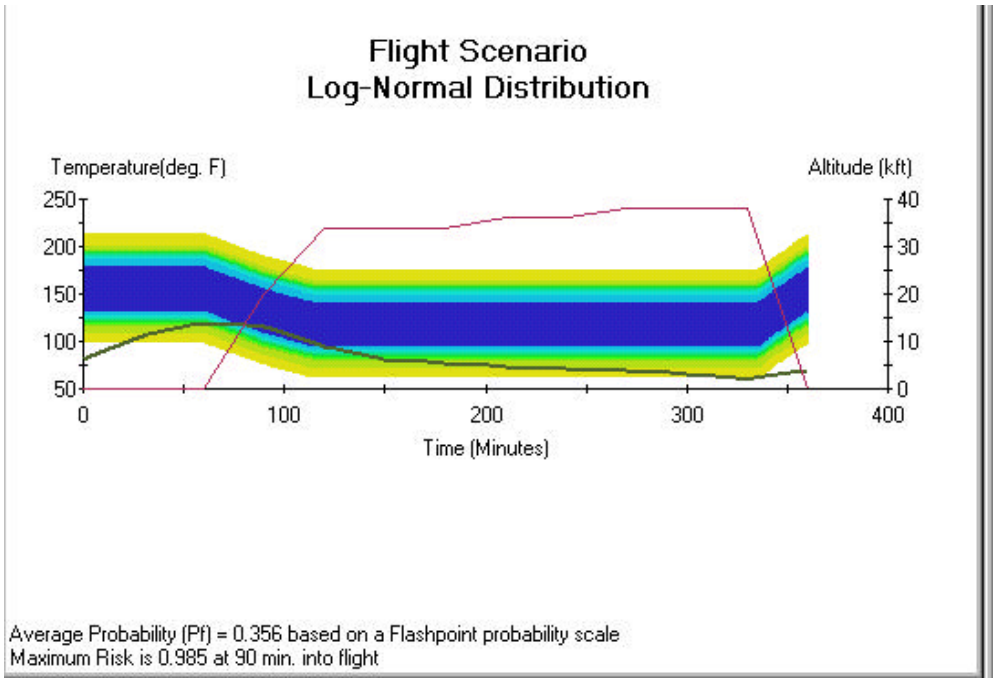
Flight scenario using single flash point and exponential distribution



Flight scenario using single flash point and lognormal distribution



Flight Scenario using flash point probability scale and exponential distribution



Flight Scenario using flash point probability scale and lognormal distribution